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Incorporation of whey products in extruded corn, potato or rice snacks☆

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Abstract

Sweet whey solids (SWS) or whey protein concentrate (WPC) were added at concentrations of 250 and 500 g/kg to corn meal, rice or potato flour to make snack products. Extrusion processing conditions included low shear, high shear, and the combination of high shear/low moisture. Increased specific mechanical energy (SME) was desired for expanding products, but SME was reduced as a result of incorporating WPC and SWS. Quality indices for expansion and breaking strength decreased significantly ($P<0.05$), indicating poor textural effects. By reducing the moisture and adding reverse screw elements, SME was increased, which increased product expansion and breaking strength. Published by Elsevier Science Ltd.

Keywords: Extrusion; Whey products; Texture; Expansion; Breaking strength

1. Introduction

Extrusion cooking provides the conditions for gelatinizing starch, polymerizing proteins and cross-linking molecules to form expandable matrices (Rossi & Peri, 1980). The addition of proteins to starches increases sites for cross-linking and affects textural quality. The source of milk protein, the concentration and processing conditions are significant factors in the cross-linking and complexing of the molten material in the extruder (Aboagye & Stanley, 1987). Ideally, proteins are denatured, re-aligned, and complexed to form expanded matrices; however, the degree of expansion depends on the concentration of protein (Aboagye & Stanley, 1987).

Extrudate expansion and texture also depend on the interaction of shear, heat, and moisture in the extruder (Mercier, 1979; Owusu-Ansah, van de Voort, & Stanley, 1984). Screw configuration, speed, and the addition of reverse screw elements, increase shear and control energy distribution responses such as melt temperature, torque and pressure; and the melt temperature then determines the degree of puffing (Sokhey, Kollengode, & Hanna, 1994). Structure of the extrudate is formed in the extruder during mechanical shear (Holay & Harper, 1982). Controlling the process responses such as SME effectively, increases expansion, which increases the crispness of the expanded products (Gogoi, Oswalt, & Choudury, 1996). Moisture exerts a great influence on extrudate quality; by affecting cell structure, moisture influences fragility of expanded products (Kitabatake, Megard, & Cheftel, 1985; Mercier, 1979; Miller, 1985).

Overall utilization of whey products in foods is still 55% of total whey produced (Whey Products, 1997). Successful incorporation of whey into extruded products will increase utilization of whey products and improve the nutrient density of snacks by increasing the protein content. Typically, snacks contain a significant portion of starch, mostly from corn, but also from wheat, rice, potato, and others. Therefore, the purpose of this study was to determine the effect of incorporating whey products into selected extruded snacks.

2. Materials and methods

Corn meal, potato flour, rice flour, whey protein concentrate (WPC), and sweet whey solids (SWS) were purchased from a commercial supplier (J. M. Swank Co. North Liberty, IA). Proximate compositions of the

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materials are presented in Table 1. A Werner Pfleiderer ZSK-30 twin screw extruder (Werner Pfleiderer Co. Ramsey, NJ) with smooth barrels was used to puff the corn, rice and potato blends. The extruder zones' temperatures were set at: 35, 35, 50, 75, 75, 90, 100, 110 and 125°C, respectively. The die was fitted with two circular inserts, each 3.18 mm in diameter. The screw elements were selected to offer low shear (Fig. 1) and high shear (Fig. 2), at a speed of 300 rpm. Kneading blocks were set at 45° for forwarding, and at 90° for kneading. Feed blends containing the whey proteins were conveyed into the extruder with a K-tron series 6300 digital feeder (K-tron Corp., Pitman, NJ). The feeder was set at 600 rpm, corresponding to rates of 5.4, 6.5, and 3.5 kg/h, for corn meal, potato flour, and rice flour blends, respectively. Varying feed rates led to surges in product flow with potato flour, which made extrusion difficult. Water was added through an electromagnetic dosing pump (Milton Roy, Acton, MA) at the rate of 1.0 l/h, at the third zone. Extrudates were collected after 25 min at the preset conditions. The extrudates were stored at 4°C until analyzed.

Table 1
Proximate analysis of ingredients (g /kg)[a]

Products	Corn	Potato	Rice	SWS	WPC
Carbohydrate	828	799	800	745	516
Protein	55.9	80.1	57.1	129	349
Fat	13.9	8	14.5	11	37
Ash	5	37	6	84	64.3
Moisture	98	80	120	32	36

[a] Approximate composition from USDA Handbook. SWS, sweet whey solids; WPC, whey protein concentrate.

2.1. Process conditions

Three extrusion conditions were evaluated: (1) low shear extrusion at 1.0 l/h moisture input (Fig. 1); (2) high shear extrusion (using a pair of reverse screw elements) at 1.0 l/h (Fig. 2); and (3), high shear, low moisture (0.5 l/h) extrusion (Fig. 2).

2.2. Specific mechanical energy

Specific mechanical energy (SME) was derived from the ratio of the net mechanical energy input rate to the extruder to the feed flow rate through the extruder (Sokhey et al., 1994). SME is a predictor of product expansion and is correlated one to one with melt temperature.

2.3. Breaking strength index

Breaking strength of extrudate was determined using a texture analyzer TA-XT2 (Stable Micro Systems, Surrey, England), with a 500 N load cell and a Warner–Bratzler shear cell (1-mm thick blade). The extrudates were analyzed at a cross head speed of 0.2 mm/s. Ten extrudates were assayed for each treatment. Breaking strength index (BSI) was calculated using: BSI = Peak breaking force (N)/extrudate diameter (mm).

2.4. Expansion index

The radial expansion (mm) of the extrudate, was determined with a digital caliper. Expansion indexes (EI) are derived from the division of radial expansion by the die orifice diameter (3.18 mm).

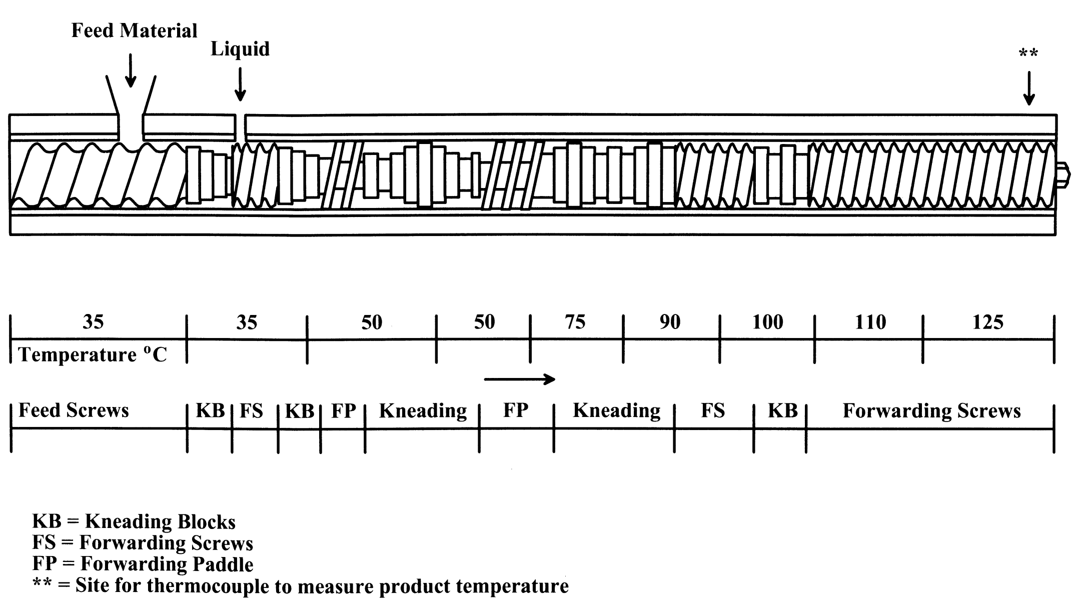

Fig. 1. Schematic representation of low shear screw configuration.

2.5. Statistical analysis

A full factorial design (3×2) of corn, rice and potato blended with either WPC or SWS was replicated. Analysis of variance was used to identify statistical differences in physical properties at selected processing conditions. Duncan's multiple range test was used for mean separation, and correlation coefficients were calculated at 95% confidence level. The statistical analysis system (SAS, 1996) package was used (SAS Institute Inc, Cary, NC) for all data analysis.

3. Results

3.1. Corn extrudates

The effect of extruding corn and whey products on pressure, torque, temperature are presented in Table 2. Incorporating whey products either in the form of WPC or SWS reduced pressure, torque, and temperature significantly ($P<0.05$).

Melt temperatures did not vary (120°C±2). Torque was reduced (50%) when 250 g/kg WPC was incorporated, and approximately 70% when added at 500 g/kg. Moisture content of the extruded products varied significantly ($P<0.05$). The low shear extrudates containing WPC retained more moisture (Table 2) and SWS extrudates retained less moisture than the control. The textural indicator, BSI, was higher than the control extruded corn containing 250 g/kg whey products. Extrudates containing 500 g/kg whey increased significantly in breaking strength ($P<0.05$), signifying a dense rather than crunchy product. Crunchiness is a desirable snack food quality.

Increasing extrusion shear rate increased melt temperature of the extrudates significantly ($P<0.01$). Melt temperature increased 10–19°C. Barrel pressure was reduced to 60% with 250 g/kg whey product substitution for corn, and was reduced further to about 66% at 500 g/kg whey product substitution for corn. Corn extrudates containing WPC retained more moisture than the corn alone, except for corn extrudate containing SWS added at the level of 250 g/kg. BSI was reduced with WPC incorporation in the amount of 250 g/kg, but increased significantly ($P<0.05$) when added in the amount of 500 g/kg.

With reduction of moisture during high shear extrusion of corn, further increases in melt temperatures (14–24°C) resulted; extruder pressure and torque responses increased significantly ($P<0.05$) over similar extrusion conditions at low shear. As extruded product moisture content declined, correspondingly, the extrudate quality indicator, BSI improved significantly ($P<0.01$) for WPC and SWS incorporated at 250 g/kg. There was also some improvement of pressure and torque with WPC and SWS added in the amount of 500 g/kg. Reduced BSI indicates reduced hardness, an improvement in extrudate quality.

SME integrates extrusion responses, torque, screw speed, and product flow rates, and EI is a good indicator of extrudate quality. Whey protein concentrate substitution for corn did not reduce either SME or EI as much as SWS substitution (Figs. 3 and 4). Substituting WPC in the amount of 250 g/kg and processing at low moisture, resulted in extrudates with comparable

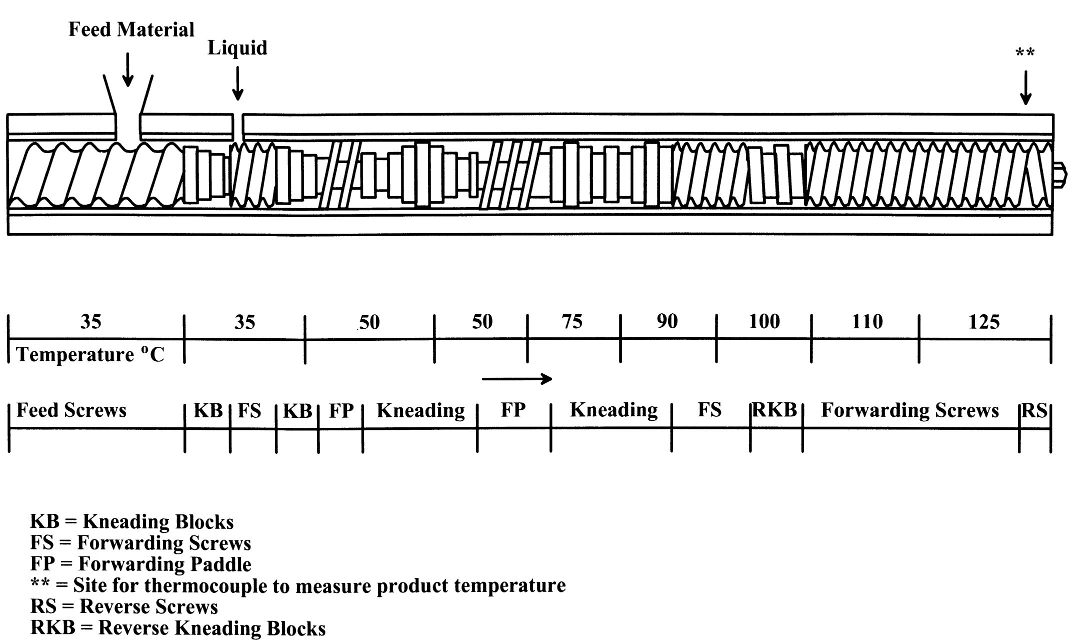

Fig. 2. Schematic representation of high shear, low moisture screw configuration.

Table 2
Extrusion process conditions for extruded corn and whey products

Product	Whey protein concentrate		500 (g/kg)	Sweet whey solids	
	0	250		250	500
Low shear[a]					
Pressure[b]	53	49	44	40	40
Torque (%)	57	25	15	26	18
Moisture (g/100 g)	13	17.5	19.6	10.3	9.4
B.S. Index	3.8	4.4	11.7	5.9	9.8
High shear					
Melt temperature[c]	139	137	130	134	131
Pressure	218	90	72	95	74
Torque (%)	70	32	16	33	19
Moisture (g/100 g)	13.1	15.4	14.1	11.8	16.1
B.S. Index[e]	3.4	2.8	9.5	3.0	11.6
Low moisture[d]					
Melt temperature	139	141	136	144	134
Pressure	218	170	92	210	155
Torque (%)	70	64	41	62	39
Moisture (g/100 g)	13.1	11.4	13.7	11.4	10.8
B.S. Index	3.4	2.4	8.0	1.2	6.4

[a] Melt temperature for low shear is 120±2°C. PSD, pooled standard deviation; Moisture=0.6; Breaking Strength=1.2.
[b] Pressure (psi).
[c] Temperature (°C).
[d] High shear — low moisture.
[e] B.S. Index, breaking strength index, N/mm.

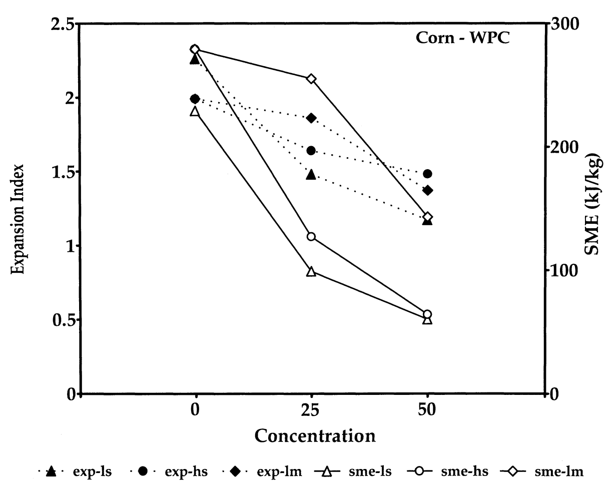

Fig. 3. Expansion index and specific mechanical energy for corn meal and whey protein concentrate. ▲: Exp-ls: expansion- low shear; ●, Exp-hs: expansion-high shear. ◆, Exp-lm: expansion-low moisture; &Delta,: SME-ls: specific mechanical energy-low shear; ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm, specific mechanical energy-low moisture.

expansion with corn alone. The combination of high shear and low moisture extrusion conditions demonstrated improved extrudate expansion with the substitution of WPC or SWS for corn meal in the amount of 250 g/kg.

3.2. Potato extrudates

Properties of potato containing either WPC or SWS extrudates are presented in Table 3. Substituting either WPC or SWS for potato reduced pressure, torque, and melt temperature significantly ($P<0.05$).

Incorporating WPC into potato extrudates at low shear reduced process pressure minimally. Reduction in torque was less than 10% for WPC and less than 14% for SWS at 250 g/kg. At 500 g/kg, both WPC and SWS substitution for potato reduced torque, with further reduction of 15 and 37% with WPC and SWS, respectively. Moisture content of the potato extrudates containing WPC or SWS increased significantly ($P<0.05$); the extrudates containing WPC or SWS retained more moisture compared with potato extrudates. Water retention increased more with WPC, while moisture decreased slightly for SWS when substituted for potato at the level of 500 g/kg. BSI for potato extrudates substituted with 250 g/kg WPC decreased slightly reflecting a softer extrudate. With SWS, BSI increased significantly ($P<0.01$) at both concentrations. Melt temperatures remained the same for all extrudates (120°C±2) at low shear extrusion conditions.

Increasing the shear rate increased torque and temperature responses significantly ($P<0.01$). Melt temperature of the extrudates increased 11–18°C. Pressure was reduced to 45% when WPC or SWS was substituted for potato in the amount of 250 g/kg, and decreased further to about 60% when WPC or SWS was substituted for potato in the amount 500 g/kg. Also, there were significant reductions in torque with the increased shear with WPC or SWS substitution for potato. Extruded potato flour with WPC or SWS incorporated, retained significantly more moisture than potato alone, with moisture retention increasing as levels of WPC or SWS in the extrudates increased. In general, BSI of potato extrudates increased during the high shear process. Substituting WPC or SWS increased BSI very significantly ($P<0.01$).

Reducing extrudate moisture during high shear extrusion, did not change melt temperatures, but, extrusion pressure and torque increased. The rate of moisture loss increased for the extrudates, while extrudate breaking strength decreased. Moisture loss and increase in pressure and torque was significant ($P<0.05$), and is an improvement in quality over potato flour extrudates that do not contain whey proteins.

SME of potato extrudates declined with increasing concentration of whey proteins except for SWS at low moisture/high shear (Figs. 5 and 6). Expansion indices for potato extrudates containing WPC did not vary for low moisture and high shear extrusion. Expansion indices were higher for whey protein substituted potato extrudates than the extrudates that did not contain whey proteins during high shear extrusion, which is a anomalous (Fig. 6), perhaps due to significantly ($P<0.05$) higher pressures than usual (Table 3). Adding 250 g/kg WPC to potato flour and processing at low moisture, produced extrudates with comparable expansion to the control (100% potato flour). The high shear and low moisture processing conditions resulted in improved snack properties of extrudates combining potato and whey proteins.

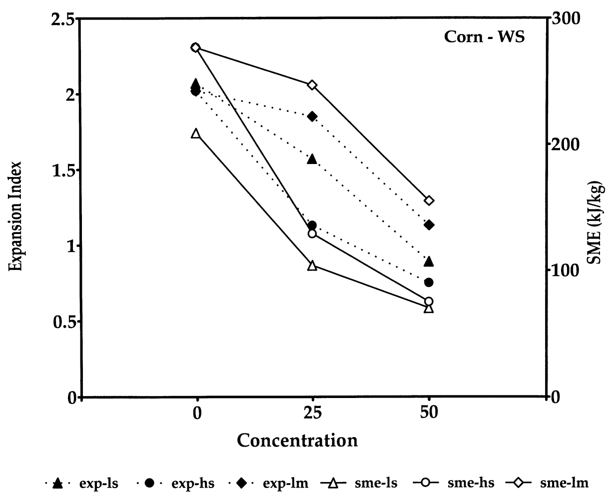

Fig. 4. Expansion index and specific mechanical energy for corn meal and sweet whey solids. ▲, Exp-ls; expansion-low shear; ●, Exp-hs; expansion-high shear; ◆, Exp-lm; expansion-low moisture; Δ, SME-ls: specific mechanical energy-low shear. ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm: specific mechanical energy-low moisture.

Table 3
Extrusion process conditions for extruded potato and whey products*

Product	Whey protein concentrate		500 (g/kg)	Sweet whey solids	
	0	250		250	500
Low shear[a]					
Pressure[b]	55	55	50	55	46
Torque (%)	82	77	62	71	52
Moisture (g/100 g)	14.2	15.1	16.5	17.6	15.7
B.S. Index	3.1	2.7	3.2	13.0	12.2
High shear					
Melt temperature[c]	136	134	131	132	135
Pressure	190	100	70	110	85
Torque (%)	82	64	44	59	52
Moisture (g/100 g)	13.2	14.2	17.8	15.1	20.6
B.S. Index	8.6	16.3	17.6	13.7	30.8
Low moisture[d]					
Melt temperature	136	137	130	137	130
Pressure	190	130	170	155	245
Torque (%)	82	76	70	84	82
Moisture (g/100 g)	13.2	14.0	11.3	12.7	13.3
B.S. Index	8.6	5.7	4.2	16.3	5.2

[a] Melt temperature for low shear is 120±2°C. PSD, Pooled standard deviation; Moisture = 0.7; Breaking Strength = 1.9. *500 RPM feed rate; 40/22 pump rate. B.S. Index, breaking strength index, N/mm.

[b] Pressure (psi).

[c] Temperature (°C).

[d] High shear — low moisture.

3.3. Rice flour

Pressure and torque responses for extruded rice flour and whey proteins are presented in Table 4. Incorporating WPC or SWS into rice flour extrudates did not change extrusion pressure during low shear processing. Torque was reduced to about 26% for rice extrudates containing 250 g/kg whey proteins, and approximately 68% for extrudates containing 500 g/kg. Moisture content of the extrudates did not change, but the textural indicator, BSI demonstrated significant increases for extrudates containing WPC and SWS at both concentrations ($P<0.05$). Melt temperatures of the rice extrudates (120°C ± 2) remained constant.

Extruding rice with increased shear increased melt temperature minimally (7–9°C), but extrusion pressure increased significantly ($P<0.01$), compared with low shear extrusion. For both whey proteins, there was a slight (<18%) drop in pressure as a result of increased shear. Rice flour extrudates containing whey proteins retained more moisture than rice flour extrudates, except for extrudates containing SWS at a concentration of 500 g/kg, which retained less moisture. BSI was reduced with WPC incorporation, but increased significantly ($P<0.01$) for extrudates containing 250 g/kg SWS. Addition of whey proteins resulted in the formation of glassy products with increased hardness. Reducing moisture during high shear extrusion increased melt temperature slightly for rice extrudates (18–20°C), pressure and torque. Extruded product moisture content dropped significantly, while the product quality indicator, BSI improved significantly ($P<0.05$) for whey proteins incorporated at a concentration of 250 g/kg.

With the high shear and low moisture combination, the undesirable effects of adding whey proteins to extrudates even at a high concentration of 500 g/kg are eliminated. The extrudate quality indicator, SME increased significantly ($P<0.05$) with increased shear and reduced moisture conditions (Figs. 7 and 8). The negative effect of adding whey proteins, such as reduced SME was totally reversed, resulting in extrudates containing whey proteins being softer and crispier than extrudates not containing whey proteins. Although expansion indices, BSI declined, the products were crispier.

4. Discussion

The effects of incorporating whey proteins in significant quantities (250 or 500 g/kg) into extrudates of corn, rice or potato depended on the type of flour, and, to a lesser extent, on the extrusion conditions. Shear and SME was increased by changing screw configuration which reduced moisture and increased extrudate expansion. Increased moisture influenced the rheological behavior of the food material in the extruder by reducing shear load (Harper, 1989). Increases in moisture enhanced the plasticity of the viscous dough, leading to reduced die pressure (Bhattacharya & Hanna, 1987; Chinnaswamy & Hanna, 1988; Kondury, Karim, & Harper, 1986; Moreira, Srivastava, & Gerrish, 1990).

Low shear, high shear and high shear and low moisture extrusion conditions affect torque, pressure and melt temperature which changes extrudate quality characteristics. Process response is dependent on process input such as screw speed and moisture (Harper, 1989). Low

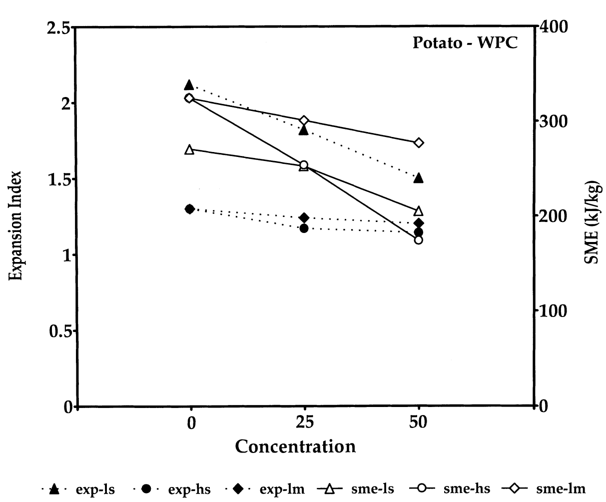

Fig. 5. Expansion index and specific mechanical energy for potato flour and whey protein concentrate. ▲, Exp-ls: expansion-low shear; ●, Exp-hs: expansion-high shear; ◆, Exp-lm: expansion-low moisture. △, SME-ls: specific mechanical energy-low shear; ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm: specific mechanical energy-low moisture.

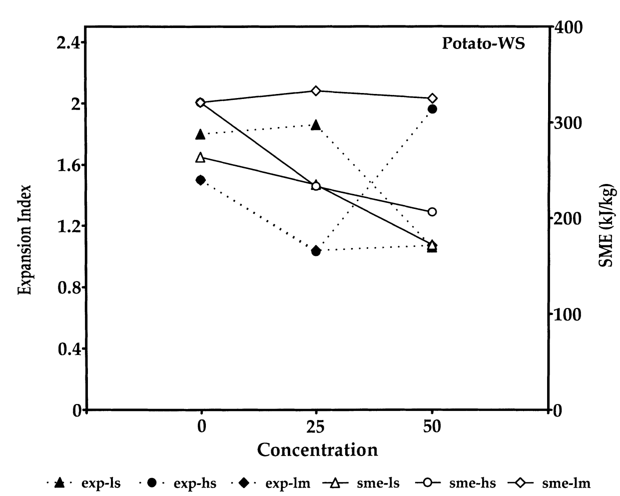

Fig. 6. Expansion index and specific mechanical energy for potato flour and sweet whey solids. ▲, Exp-ls: expansion-low shear; ●, Exp-hs: expansion-high shear; ◆, Exp-lm: expansion-low moisture. △, SME-ls: specific mechanical energy-low shear; ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm: specific mechanical energy-low moisture.

Table 4
Extrusion process conditions for extruded rice and whey products

Product	Whey protein concentrate		500 (g/kg)	Sweet whey solids	
	0	250		250	500
Low shear[a]					
Pressure[b]	51	51	49	50	41
Torque (%)	36	29	17	24	13
Moisture (g/100 g)	21.4	22.7	20.2	22.4	20.1
B.S. Index	16	20.9	23.7	23.7	30.7
High shear					
Melt temperature[c]	125	127	129	129	128
Pressure	70	55	55	65	50
Torque (%)	40	34	14	29	13
Moisture (g/100 g)	20.8	19.3	24.3	20.7	16.2
B.S. Index	10.6	4.5	8.0	5.7	12.8
Low moisture[d]					
Melt temperature	125	138	140	140	138
Pressure	70	95	120	105	95
Torque (%)	40	60	55	47	36
Moisture (g/100 g)	20.8	14.3	12.0	12.8	10.9
B.S. Index	10.6	2.9	5.7	4.5	6.5

[a] Melt temperature for low shear is 120±2°C. PSD; Pooled standard deviation; Moisture=0.7; Breaking Strength=2.3. B.S. Index: Breaking strength index, N/mm.
[b] Pressure (psi)
[c] Temperature (°C).
[d] High shear — low moisture.

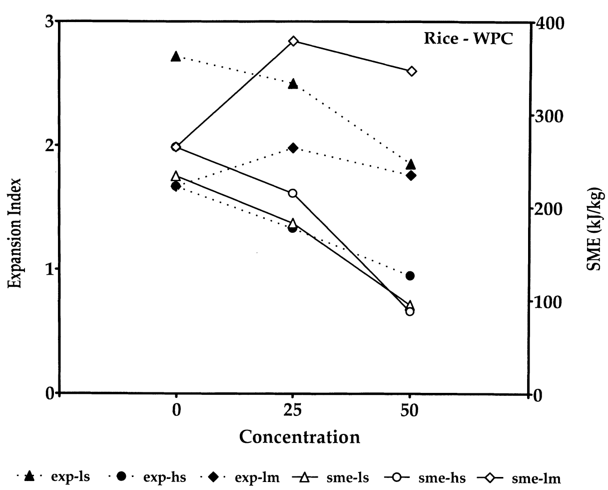

Fig. 7. Expansion index and specific mechanical energy for rice flour and whey protein concentrate. ▲, Exp-ls: expansion-low shear; ●, Exp-hs: expansion-high shear; ◆, Exp-lm: expansion-low moisture. Δ, SME-ls: specific mechanical energy-low shear; ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm: specific mechanical energy-low moisture.

moisture extrusion increases extrudate expansion (Davidson, Patton, Diosady, & Larrocque, 1984; Miller, 1985). Changing the screw configuration by adding reverse screw elements, increased SME and other responses, and improved extrudate characteristics. Extrudate expansion (Barres, Vergnes, Tayeb, & Della Valle, 1990; Edmire, Edwards, & McCarthy, 1992; Kirby, Ollett, Parker, & Smith, 1988) and specific mechanical energy increased (Gogoi et al., 1996).

The effect of extrusion processing on extrudate expansion depends to a large extent on the flour. Expansion of single component extrudates is being studied extensively for corn meal (Gomez & Aguilera, 1984; Chinnaswamy, Hanna, & Zobel, 1989; Kirby et al., 1988; Onwulata, Mulvaney, & Hsieh, 1994); potato (Della Valle, Tayeb, & Melcion, 1987) and rice (Gogoi et al., 1996; Grenus, Hsieh, & Huff, 1993). Limited data are available on the use of whey products with flours.

The extrudate properties are generally unpredictable when milk proteins are incorporated in flours (Singh, Nielsen, Chambers, Martinez-Serna, & Villota, 1991). Kim and Maga (1987) reported that substituting WPC (200 g/kg) for either corn or potato flours in extrudates reduced expansion, but that WPC (200 g/kg) substituted for rice flour increased extrudate expansion significantly. Our results demonstrate no increase in expansion for rice flour extrudates as a result of adding whey proteins. The lactose content of the whey proteins may have contributed to reduction in expansion. Sugar is reported to reduce expansion (Barret, Kaletunc, Rosenburg, & Breslauer, 1995; Fan, Mitchell, & Blanshard, 1996). By changing extrusion shear and moisture conditions, desirable textural qualities resulted, and at low moisture content, expandable, high whey content extrudates with increased expansion were created. Whey protein isolates (>90% protein or more) may be substituted for

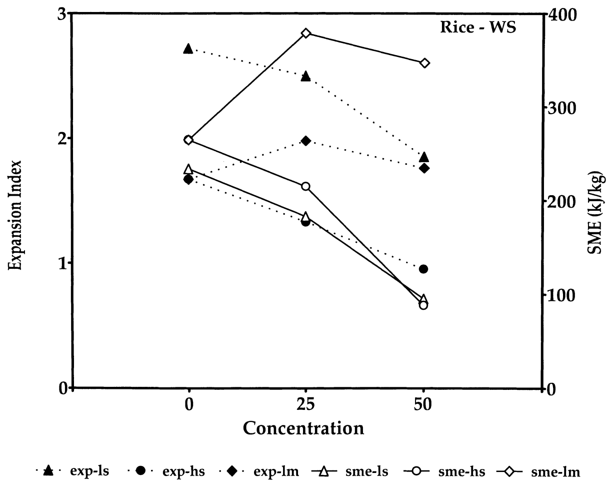

Fig. 8. Expansion index and specific mechanical energy for rice flour and sweet whey solids. ▲, Exp-ls: expansion-low shear; ●, Exp-hs: expansion-high shear; ◆, Exp-lm: expansion-low moisture; Δ, SME-ls: specific mechanical energy-low shear; ○, SME-hs: specific mechanical energy-high shear; ◇, SME-lm: specific mechanical energy-low moisture.

WPC or SWS, to eliminate possible effect of lactose to reduce extrudate expansion.

5. Conclusion

Extrusion process parameters such as the specific mechanical energy, expansion indices and breaking strength indicators described product quality of extrudates of corn, rice, or potato flours extruded in combination with whey proteins. Extrudates with good quality were produced with up to 25% whey protein substitution for flour. Breaking strength indices for acceptable extrudates were lower than the non whey protein substituted extrudates, but without corresponding increases in expansion indexes. An acceptable snack that incorporates whey proteins such as whey protein concentrate or sweet whey solids can be produced though the extrudates may not be significantly expanded.

Acknowledgements

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